Point-of-Care Ultrasound Integrated Into a Staged Diagnostic Algorithm for Pediatric Appendicitis

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Objectives: We hypothesized that point-of-care ultrasound (POCUS) is as accurate as radiology-performed ultrasound in evaluating children with clinical concern for appendicitis. As part of a staged approach, we further hypothesized that POCUS could ultimately decrease computed tomography (CT) utilization.

Methods: This was a prospective, convenience sampling of patients aged 2 to 18 years presenting with abdominal pain to a pediatric emergency department. Those patients with prior abdominal imaging, pregnant, or unable to tolerate the examination were excluded. An algorithm was followed: POCUS was first performed, followed by a radiology-performed ultrasound, and then a CT as necessary. The main outcome measure was the accuracy of the POCUS in diagnosing of appendicitis. This was compared with radiology-performed ultrasound. We also examined whether certain patient or clinical characteristics influenced the performance of POCUS. Lastly, we determined the amount by which CT scans were decreased through this staged algorithm.

Results: Forty patients were enrolled and underwent a POCUS examination. A total of 16 (40%) had pathology-confirmed appendicitis. Point-of-care ultrasound had a sensitivity of 93.8% (95% confidence interval [CI], 69.7%–98.9%) and specificity of 87.5% (95% CI, 67.6%–97.2%). Radiology-performed ultrasound had a sensitivity of 81.25% (95% CI, 54.3%–95.7%) and specificity of 100% (95% CI, 85.6%–100%). The radiology-performed and POCUS examinations had very good agreement ($\kappa = 0.83$, $P < 0.0005$). Patient characteristics including body mass index did not have an affect on the POCUS. However, POCUS identified all patients with an Alvarado score higher than 6. Overall, the reduction in CT examinations was 55%.

Conclusions: In pediatric patients presenting with clinical concern for acute appendicitis, a staged algorithm that incorporates POCUS is accurate and has the potential to decrease CT scan utilization.

Key Words, point-of-care ultrasound, appendicitis, abdominal pain, ultrasound, ionizing radiation

(*Pediatr Emer Care* 2016;00: 00–00)

Appendicitis is the most common surgical emergency among children presenting to emergency departments (EDs) with abdominal pain.[1–3] Children with appendicitis present a particular diagnostic dilemma, and as a result, misdiagnoses are as high as 28% to 57% in children younger than 12 years of age.[4–8] Misdiagnoses come at the expense of time delay, which has been shown to be directly proportional to risk of appendiceal perforation and higher morbidity.[9–12] Clinical judgment alone is suboptimal because history, physical examination, and laboratory testing are often imprecise and inaccurate.[13–15]

Imaging tests such as ultrasonography, computed tomography (CT), and magnetic resonance imaging are often used to improve diagnostic accuracy.[16] Interestingly, compared with inpatient observation and serial basic laboratory testing, imaging is relatively inexpensive.[17] However, while CT scans offer a high accuracy, with sensitivities 87% to 100% and specificities 83% to 97%,[18] they expose children to significant amounts of ionizing radiation, which ultimately can increase the risk for developing cancers.[19] To avoid ionizing radiation, radiologist-performed ultrasound began to be used as an alternative imaging modality.[19–21] However, this is largely operator dependent with sensitivities and specificities varying widely.[18] Unfortunately, not all centers have 24/7 availability of radiology personnel and ultrasound, which often leads to a delay in diagnosis, increased morbidity, greater expense, and a greater utilization of CT scans. As a possible solution, point-of-care ultrasound (POCUS) has been utilized in adult patients to enhance clinical decision making and diagnostic accuracy for a number of pathological entities, especially when radiology-performed ultrasound is unavailable.[22] More recently, this technology has been introduced into the pediatric ED.[23] One such application includes POCUS as a viable imaging modality for the evaluation of acute appendicitis.[24]

Given the limitations of the clinical examination, laboratory studies, and imaging modalities alone, a staged imaging approach has been suggested,[25–27] which has been shown to decrease exposure to ionizing radiation without the expense of decreasing diagnostic accuracy.[26,27] However, this staged approach has never included a POCUS. Therefore, we performed a study assessing the accuracy of POCUS compared with that of radiology-performed ultrasonography for the evaluation of pediatric appendicitis as part of a staged imaging algorithm. Secondary outcome measures include the accuracy of POCUS when compared with patient characteristics and clinical presenting factors. Finally, we evaluated the potential decrease of CT scan utilization.

METHODS

Study Setting and Population

A prospective cohort study was conducted at a tertiary care level 1 academic ED with an annual census of 13,000 pediatric visits. A convenience sample of patients was recruited when a trained physician sonographer was present. Written informed consent and assent were obtained. This study was approved by the hospital's institutional review board. Eligible patients were recruited between October 2009 and June 2010.

There were 3 participating physician investigators: an emergency medicine resident, a fellowship-trained emergency ultrasound attending physician, and an ultrasound fellowship-trained pediatric emergency attending physician. Each physician investigator had training in POCUS. They received a 30-minute appendicitis ultrasound tutorial prior to performing the examinations. Before enrolling patients, each physician performed a minimum of 40 scans that were reviewed for quality assurance by fellowship-trained ultrasound faculty. During the daytime hours, radiology-performed ultrasound examinations were performed by ultrasound technicians and overread by attending radiologists. In the evening, radiology-performed ultrasound examinations were performed and interpreted by radiology resident and

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Disclosure: The authors declare no conflict of interest.
Reprints not available from authors.

ISSN: 0749-5161

Symptoms, Signs, Laboratory Findings	Score
Migratory right iliac fossa pain	1
Nausea/Vomiting	1
Anorexia	1
RLQ tenderness	2
Rebound tenderness	1
Elevated temperature	1
Leukocytosis (>10,000/uL)	2
Neutrophil Shift (>75%)	1

FIGURE 1. The Alvarado score. The Alvarado score is a scoring system used to predict probability of appendicitis. Each patient is assigned a score from 1 to 10 based on historical, physical examination, and laboratory variables. In the equivocal clinical presentation (scores 4-6), adjunctive imaging is recommended. With an Alvarado score of 7 or higher, surgical consultation is recommended. With Alvarado scores of 3 or lower, CT is not generally indicated.[40]

attending physicians. When examinations were performed by radiology residents, they were overread by attending radiologists the following morning.

Eligible patients were those aged 2 to 18 years presenting with abdominal pain and clinical concern for acute appendicitis, as determined by the treating attending physician. Exclusion criteria included patients aged younger than 2 years or older than 18 years, pregnant patients, those referred into the ED with prior abdominal imaging, those patients unable to tolerate the examination, and those unwilling or unable to provide informed consent.

Study Protocol

The treating physician performed a routine history and physical examination. In situations where there was clinical suspicion for acute appendicitis, laboratory studies and diagnostic imaging studies were ordered at the discretion of the treating clinician. Patient demographics and elements of the history and physical examination were recorded, and the patient was assigned an Alvarado score (Fig. 1). A POCUS was then conducted as the first step before initiating the institutional standard of a staged diagnostic algorithm. This algorithm started with a radiology-performed ultrasound, and then proceed to CT if the appendix was not visualized or there was an equivocal study (Fig. 2). This imaging pathway was established in 2003 as collaboration between the departments of pediatric radiology, emergency medicine, and pediatric surgery to reduce radiation exposure.

Analgesia was administered to the patient before the POCUS evaluation, at the discretion of the treating clinician. Emergency physicians used a Sonosite M-Turbo (Bothell, Wash) with an 8- to 10-MHz linear transducer. Patients were evaluated using a scanning protocol, in which the clinician sonographer started in the

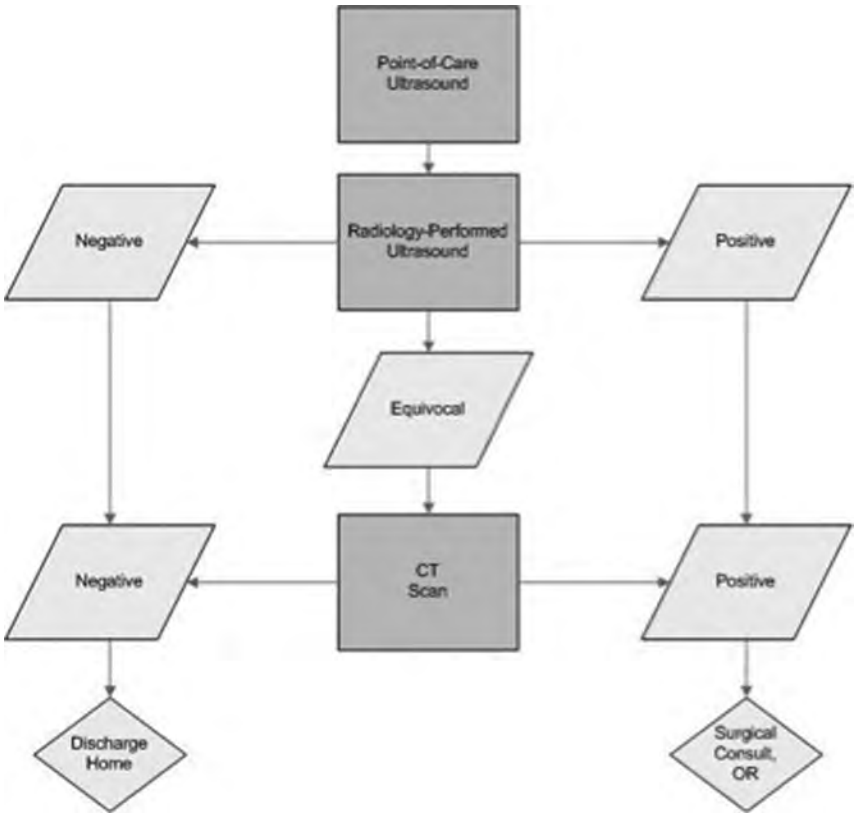

FIGURE 2. Staged algorithm that incorporates "ultrasound first" to decrease radiation utilization for pediatric appendicitis. The clinician first performs a POCUS. This is followed by a radiology-performed ultrasound. In those patients who have a negative ultrasound, surgery is consulted. In those who have a negative ultrasound, patients are discharged home. For those ultrasound studies that are equivocal in which the appendix is not visualized, a CT scan is performed.

right lower quadrant. In those patients who could specify their point of maximal pain, the sonographer began in that location. The linear transducer was placed with the indicator oriented toward the patient's right side. The landmarks of the psoas muscle and the iliac artery and vein were identified, and scanning proceeded medial and lateral to these landmarks (Fig. 3). During interrogation of these regions, graded compression was performed, a technique in which constant pressure is generated by the transducer to displace gas and soft tissue.[28] Once the appendix was identified in the transverse plane, the transducer was then rotated, to visualize the appendix in the longitudinal plane. A "positive" POCUS examination included the visualization of the entire appendix as a blind-ended noncompressible tubular structure, measuring greater than 6 mm in diameter, without peristalsis (Fig. 4).[29,30] Secondary findings of appendicitis were noted and included the presence of periappendiceal inflammation, appendicolith, or free fluid. An "equivocal" study resulted from the nonvisualization or incomplete visualization of the appendix. To be a "negative" study, the appendix needed to be visualized in its entirety, be compressible, measure less than 6 mm, and have no surrounding edema or free fluid.[28] As part of the staged algorithm, if the appendix was definitively positive or negative, no further imaging was necessary. A CT scan was considered in equivocal cases in which the appendix was not visualized.

Measurements

The main outcome measure was the accuracy of the POCUS in the diagnosis of appendicitis. The accuracy of the POCUS for appendicitis was compared with radiology-performed ultrasonography. Both the POCUS and radiology-performed ultrasonography were further evaluated for accuracy based on results of CT scans, surgical consultation, pathology reports, discharge diagnoses, and telephone follow-up.

Those subjects who were discharged home from the ED with a negative evaluation for appendicitis received telephone follow-up at least 2 weeks but no later than 12 months after discharge. Participants were considered as negative for acute appendicitis if they were discharged from the hospital with a diagnosis other than acute appendicitis.

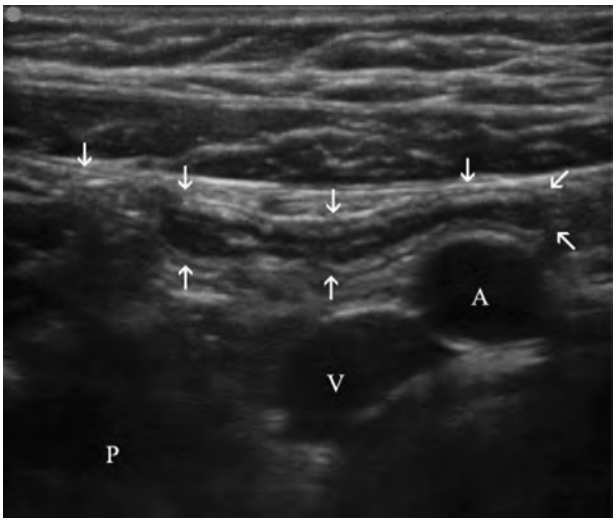

FIGURE 3. Longitudinal view of a normal appendix (arrows). Note adjacent landmarks of the psoas muscle (P), iliac artery (A), and iliac vein (V).

FIGURE 4. Appendicitis, transverse view with the measurement performed anterior-posterior.

Data Analysis

Data were analyzed using SAS version 9.4 software (SAS Institute, Cary, NC). Demographic and baseline data were calculated using means (SDs) and proportions. Test performance characteristics were calculated for sensitivity, specificity, positive likelihood ratio (LR+), and negative likelihood ratio (LR−), with 95% confidence intervals (CIs). For purposes of calculating test characteristics, ultrasound examinations that were nondiagnostic or equivocal were coded as negative results.[24,31,32] Descriptive statistical analyses were used for categorical data.

RESULTS

Clinician investigators identified and approached 40 potential study subjects; no patients refused to participate in the study (Fig. 5). No patients enrolled were lost to follow-up, and all were considered for the final data analysis. Descriptive statistics of the study population are reported in Table 1.

All enrolled patients underwent both a POCUS and a radiology-performed ultrasound. Of the 40 patients enrolled, a total of 16 (40%) underwent appendectomy (Fig. 5), and there were 16 (100%) of 16 cases of pathology-confirmed appendicitis. Point-of-care ultrasound took the clinician an average of 6 minutes to perform (range, 2–10 minutes). The POCUS correctly identified 15 (93.75%) of 16 (CI, 69.7%–99.0%) patients with appendicitis; the remaining case was considered an equivocal scan, in which the appendix was not visualized. In comparison, radiology-performed ultrasound identified 13 (81.3%) of 16 (CI, 54.3%–95.7%) patients

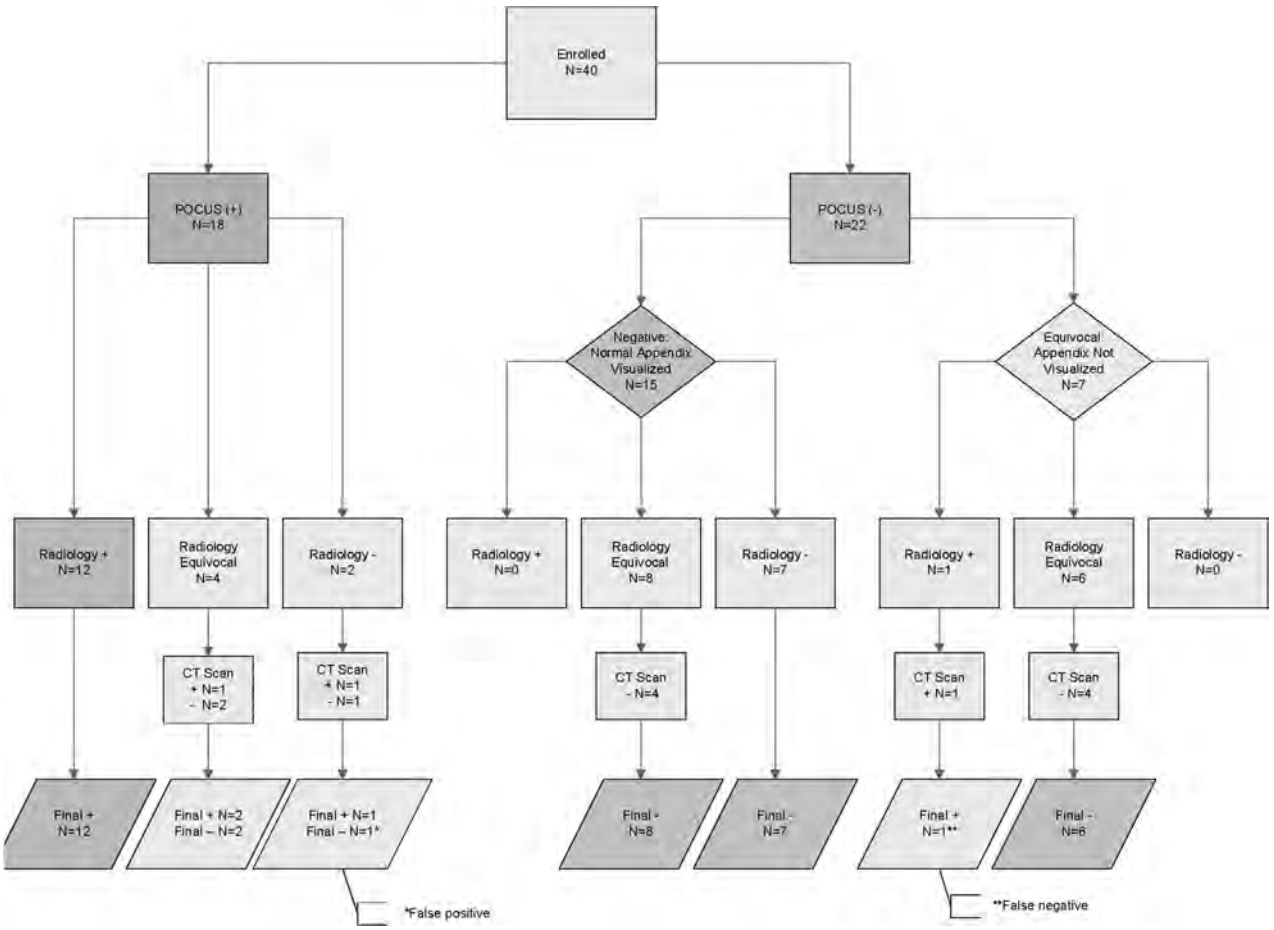

FIGURE 5. Study flow chart. Rad, radiology-performed ultrasound; +, positive; –, negative; n, number of patients.

with appendicitis, with 3 false-negative studies. Interestingly, the 3 false-negative studies noted on the radiology-performed ultrasound were read as a positive POCUS examination. A total of 18 (45%) of 40 patients received imaging via CT. Twenty-four patients were discharged home without surgical intervention. For POCUS, results included 3 false-positive studies and 1 false-negative study (Fig. 5). To our knowledge, no cases of appendicitis were missed given our 100% phone follow-up rate.

The test characteristics for POCUS and radiology-performed ultrasound to detect appendicitis are reported in Table 2. Point-of-care ultrasound had a sensitivity of 93.8% (95% CI, 69.7%–98.9%) and specificity of 87.5% (95% CI, 67.6%–97.2%). Radiology-performed ultrasound had a slightly lower sensitivity of 81.25% (95% CI, 54.3%–95.7%), but a higher specificity of 100% (95% CI, 85.6%–100%). The POCUS had very good agreement with that of radiology-performed ultrasound, with a κ of 0.83 ($P < 0.0005$). The clinician sonographer visualized the appendix in 33 cases (82.5%) on POCUS. In those cases, the sensitivity was 100% (95% CI, 78.0%–100%) and the specificity was 83.3% (95% CI, 58.6%–96.2%). For the radiology-performed ultrasound, the appendix was visualized in only 22 cases (55%). In those cases, the sensitivity was 92.9% (95% CI, 66.1%–98.8%) and the specificity was 100% (95% CI, 66.2%–100%). Because ultrasonography is largely operator dependent, and presumably performance characteristics improved over time, we stratified the patients into 2 groups based on the time of enrollment. When comparing the first half with the second half of enrolled patients, sensitivity increased from 87.5% (95% CI, 47.4%–97.9%) to 100% (95% CI, 69.0%–100%) and the specificity increased from 75% (95% CI, 42.8%–94.2%) to 100% (95% CI, 69.0%–100%). Moreover, from the first to the second half of the study, the number of false-positive studies decreased from 3 to 0.

For the secondary objectives, we investigated whether certain patient demographics or clinical features had an effect on the results. Patient age and body mass index (BMI) did not have an effect on the POCUS. With regards to the patients' clinical presentations, 13 patients were classified as “low risk,” with an Alvarado score of less than 6. There were 2 low-risk patients who were ultimately diagnosed with appendicitis; both patients were correctly identified by both point-of-care and radiology-performed ultrasound. Of the 21 patients that were classified as “high risk” with an Alvarado score higher than 6, only 12 were ultimately diagnosed with appendicitis. Point-of-care ultrasound was able to accurately rule out appendicitis in all but 3 patients. Of note, all of the 3 false-positive POCUS studies were in patients with Alvarado scores higher than 6. Of the 12 high-risk patients that ultimately had appendicitis, all were identified by POCUS; all but 3 were identified by radiology-performed ultrasound.

The number of CT examinations avoided was determined by the number of patients who followed the algorithm and did not ultimately have a CT performed. Of the 40 patients enrolled in the study, 14 (35%) had CT imaging (Fig. 5). Before the initiation of this staged algorithm, these patients would have received CT examinations. Therefore, in this staged algorithm, because

TABLE 1. Demographic, Clinical, and Sonographic Characteristics for Patients With and Without Appendicitis

Characteristics	Appendicitis (n = 16)	Without Appendicitis (n = 24)
Age, median (IQR), y	10.7 (7.6–13.8)	8.3 (4–12.6)
Sex male, n (%)	6 (38)	14 (58)
BMI (95% CI)	20.8 (16.8–24.8)	19.1 (12.5–25.7)
Symptom duration, median (IQR), h	43.9 (18.2–69.6)	39.8 (8–71.6)
Fever, n (%)	6 (38)	14 (58)
Nausea, n (%)	12 (75)	14 (58)
Vomiting, n (%)	12 (75)	16 (67)
Anorexia, n (%)	12 (75)	11 (46)
RLQ tenderness, n (%)C	16 (100)	18 (78)
Rebound, n (%)	8 (50)	2 (9)
WBC, median (IQR), $\times 10^3/\mu L$	15.5 (10.8–20.2)	13.0 (5.8–20.2)
Alvarado score, median (95% CI)	7.7 (6.2–9.2)	5.6 (3.8–7.4)
Sonographic findings		
Visualization of the appendix, n (%)	15 (93)	19 (79)
Sonographic McBurney's sign, n (%)	14 (88)	12 (50)
Periappendiceal inflammation, n (%)	13 (81)	1 (4)
Free fluid, n (%)	5 (33)	6 (25)
Compressibility, n (%)	1 (6)	16 (72)

IQR, interquartile range; RLQ, right lower quadrant; WBC, white blood cell count.

the radiology-performed examination superseded the POCUS examination, there was a reduction of CT examinations in 55% of the cases. Had the clinician relied on the POCUS examination alone, there could have been a reduction of CT examinations up to 83%.

DISCUSSION

The presentation of acute appendicitis in children often presents a particular diagnostic dilemma. Though many scoring systems have been proposed, none have shown to have a high enough sensitivity and specificity for a reliable diagnosis alone.[32,33] As a result, we often rely on the use of imaging, which often involves ionizing radiation. However, with the recent use of ultrasound as a first-line imaging modality, diagnostic accuracy may be improved, while decreasing the use of ionizing radiation.[34] When POCUS is utilized, Fox et al[24] found a low sensitivity of 65% (95% CI, 52%–76%), and a rather high specificity at 90% (95% CI, 81%–95%), indicating that there is a potential role for POCUS, especially when radiology-performed ultrasound is unavailable. More recently, Sivitz et al[32] affirmed these findings but found a greater sensitivity of 85% (95% CI, 75%–95%) and similar specificity of 93% (95% CI, 85%–100%). In a recent study in adult patients, Mallin et al[35] found a sensitivity of 67.65% (95% CI, 49.5%–82.6%) and a specificity of 98.41% (95% CI, 91.4%–99.7%). We found POCUS to have a higher sensitivity of 93.5% but a slightly lower specificity of 87.5%, when compared with prior reported studies. We also found a false-positive rate of 7.5%, which is well within the accepted negative appendectomy rate. While the published acceptable negative appendectomy rate is less than 20%, in practice negative appendectomy rates are generally 10% to 15%.[36,37] A recent study by Bachur et al[38] showed the highest negative appendectomy rates to be in children younger than the age of 5 years and females older than the age of 10 years. Interestingly, all of our patients with a false-positive POCUS were females older than the age of 10 years. The radiology-performed ultrasound evaluations showed an equal, if not better, accuracy than current literature suggests, with a sensitivity and specificity of 81.25% and 100%, respectively. Radiology-performed ultrasound identified all but 1 patient with confirmed appendicitis. Part of this may be due to the institutional policy that all patients with suspected appendicitis required an ultrasound examination to be performed and radiology-performed ultrasound studies were available 24/7. Therefore, the ultrasound technicians were quite facile and experienced with the right lower quadrant ultrasound examinations.

Many clinicians have hypothesized that certain patient characteristics, such as the BMI would limit the performance of POCUS. A study performed by Abo et al[39] shows that as BMI increases, there was a statistically insignificant trend to lower sensitivities; however, specificity remained high. We similarly found that BMI had no effect on the ability to successfully perform ultrasound examinations in our study. This may be due in part to our small sample size and the limited number of patients with BMI greater than 25.

While several scoring systems have been developed in attempts to improve the clinical diagnostic accuracy for appendicitis,[33,40,41] they have never been evaluated in conjunction with POCUS. We were able to identify a high-risk group (Alvarado score, >6), thereby increasing the pretest probability of POCUS. Point-of-care ultrasound correctly identified all of the 14 patients who had an Alvarado score higher than 6 and ultimately had appendicitis. These data suggest a possible role for risk stratification before ultrasound evaluation.

In addition to improving diagnostic accuracy, it is the goal that instituting a staged algorithm approach will ultimately lead to the decreased utilization of CT scans and exposure to ionizing radiation. As noted in the previous literature, a CT examination is not performed if the ultrasound scan is definitively positive or negative for appendicitis.[26] This staged approach has previously been shown to reduce the number of CT examinations by 52.7%, with a sensitivity of 98.6%. When using a similar staged approach in adult patients, Mallin et al[35] found decreased the utilization of CT scans of 12%; if all positive ultrasound scans did not have CT scans performed, this had the potential to decrease

TABLE 2. Test Characteristics of POCUS and Radiology-Performed Ultrasound

Imaging Modality, n = 40	Sensitivity, % (95% CI)	Specificity, % (95% CI)	LR+ (95% CI)	LR− (95% CI)	PPV (95% CI)	NPV (95% CI)
POCUS	93.8 (69.7–98.9)	87.5 (67.6–97.2)	7.5 (2.6–21.8)	0.07 (0.01–0.48)	83.3 (58.6–96.2)	95.5 (77.1–99.2)
Radiology-performed ultrasound	81.25 (54.3–95.7)	100 (85.6–100)		0.19 (0.07–0.52)	100 (75.1–100)	88.9 (70.8–97.5)

PPV, positive predictive value; NPV, negative predictive value.

CT utilization by 24%. We found that through our staged approach, all cases of confirmed appendicitis were identified and CT scans were decreased by 55%. A recent study from our radiology department notes that a decrease in CT scanning by 52.7% when each patient is first evaluated by ultrasound.[26]

Limitations

A major limitation of this study was its small sample size. Further large scale, prospective studies are needed to validate our findings. Given the lack of trained clinician sonographers, we were unable to consecutively capture all eligible pediatric patients with the clinical suspicion for appendicitis. Our convenience sampling methods may lead to a selection bias of those patients with a higher clinical suspicion for appendicitis. Another potential source of bias was that all but 3 studies were performed by the principle investigator who is ultrasound fellowship trained, which therefore limits the generalizability of this study. The physician conducting the POCUS examination was not blinded to historical data, physical examination, or laboratory testing before performing POCUS. Though using clinical data in addition to ultrasonography may lead to a selection bias, the study was designed to reflect how POCUS is actually utilized in clinical practice.[22] Furthermore, we retrospectively evaluated times to perform the POCUS from time stamps on the ultrasound studies. This does not account for patient or machine preparation, or the total time in the ED. While POCUS may involve an investment of the physician's time upfront, it has the potential to facilitate patient flow and disposition if the POCUS reveals the diagnosis. Lastly, employing an algorithm as suggested by this study involves significant "buy in" and involvement from both the radiologists and surgeons. It truly involves a multidisciplinary approach. In our institution, we have been fortunate to have acceptance of this approach. Future large-scale, prospective studies are warranted to validate this proposed algorithm approach.

CONCLUSIONS

The test characteristics of POCUS for the detection of appendicitis are similar to those of radiology-performed ultrasonography. As a result, POCUS has the potential to serve as the initial imaging modality within a staged-algorithm for appendicitis, especially when radiology-performed ultrasonography is unavailable. This approach has the potential to decrease the utilization of CT scans and the associated harmful risks of ionizing radiation.

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